

New Constraint on Squark Flavor Mixing from ^{199}Hg EDM ^a

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ABSTRACT

We obtain a new constraint on the CP-violating flavor mixing between the left-handed top scalar quark (\tilde{t}_L) and charm scalar quark (\tilde{c}_L), by considering a chargino loop contribution to chromo-electric dipole moment of strange quark, which is limited by the electric dipole moment of the neutron and atoms. It is found that the flavor mixing should be suppressed to the level of $\mathcal{O}(0.1)$ for the CP phase of order unity. Although it is much stronger than the known constraint from the chargino loop contribution to $b \rightarrow s\gamma$, the moderate constraint we obtain here is argued to leave room for sizable supersymmetric contribution to the CP asymmetry in $B_d^0 \rightarrow \phi K^0$.

1. Introduction

Suppression of the flavor changing neutral current (FCNC) by the GIM mechanism is one of the most celebrated features of the Standard Model (SM). This mechanism is applied because of either degeneracy of the masses or small generation mixings. On the contrary, the SUSY models do not generally satisfy these conditions. Thus they tend to suffer from large FCNC. Actually, 1 – 2 and 1 – 3 generation mixings in the squark mass matrices are stringently constrained by the $K^0 - \bar{K}^0$ mixing and so on. On the other hand, 2 – 3 squark mixings are allowed to be relatively large by the known bound from $\text{Br}(b \rightarrow s\gamma)$, which provides $(\delta_{LL,RR}^d)_{23} \lesssim O(10^{-1}) - O(1)$, $(\delta_{LL}^u)_{23} \lesssim O(1) - O(10)$. Therefore we expect to detect contributions from the SUSY models by observing the transition processes of 2 – 3 generation.

Nowadays a special attention is paid to the $b \rightarrow s$ flavor mixings in B mesons. A very interesting process is the mixing-induced CP asymmetry of $B_d \rightarrow \phi K^0$, $S_{\phi K^0}$. Experimentally, the latest result of the Belle collaboration announced the deviation from the SM that [1],

$$S_{\phi K^0}(\text{Belle}) = 0.06 \pm 0.33 \pm 0.09, \quad (1)$$

while that of the BaBar collaboration [2],

$$S_{\phi K^0}(\text{BaBar}) = 0.50 \pm 0.25^{+0.07}_{-0.04}, \quad (2)$$

is consistent with the SM prediction. Though the situation is yet unclear, one certainly has to watch what is happening when more data are accumulated, and on the theoretical side it is important to investigate in what situation new physics can generate large $b \rightarrow s$ transition.

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In SUSY models, a new source of flavor mixing originates in SUSY breaking masses of squarks and sleptons. It is convenient to parameterize these squark mixing as

$$(\delta_{LL}^u)_{ij} = \frac{(m_{\tilde{u}_L}^2)_{ij}}{m_{\tilde{q}}^2}, \quad (\delta_{RR}^u)_{ij} = \frac{(m_{\tilde{u}_R}^2)_{ij}}{m_{\tilde{q}}^2}, \quad (3)$$

where $(m_{\tilde{u}_{L(R)}}^2)_{ij}$ is an (ij) element of the left-handed (right-handed) squark mass squared matrix for up-type squarks in the superCKM basis. A similar notation will be used for the down-type squarks. It is important that there is chirality structure in the squark mass matrices. The flavor mixings between the second and third generations both in left-handed squarks (LL) and in right-handed squarks (RR) have CP-violating phase generally, and thus both/either of the mixings can make contribution to $S_{\phi K^0}$.

A notable observation has recently been made in Ref. [3], which has found that the present experimental bound on the electric dipole moment (EDM) of the neutron and atoms including the mercury severely constrains the CP violating part of the squark mixings. In fact, the diagrams which have two sources of 2 – 3 generation mixings contribute to the strange-quark color electric dipole moment (CEDM) generally. Specifically they consider a product of $(\delta_{LL}^d)_{23}$ and $(\delta_{RR}^d)_{32}$. The reason is that in the presence of sizable $\tilde{b}_L - \tilde{s}_L$ and $\tilde{b}_R - \tilde{s}_R$ mixings, the dominant contribution to the CEDM of the strange quark, d_s^C , arises from the gluino-loop diagram with the $\tilde{b}_L - \tilde{b}_R$ mixing, which is proportional to $m_b \mu \tan \beta$, and thus is enhanced by m_b/m_s over the usual contribution induced by the $\tilde{s}_L - \tilde{s}_R$ mixing. On the other hand, the strange CEDM is bounded by the null measurement of the neutron and atomic EDMs. Recently the contributions of strange CEDM to the EDMs are revisited and the neutron is shown to provide the most stringent constraint, rather than the mercury [4]. As a result, the CP-violating part of the product of the squark mixings are bounded very strongly by the neutron EDM.

Although the constraint is only for the product of $(\delta_{LL}^d)_{23}$ and $(\delta_{RR}^d)_{32}$, radiative corrections (renormalization group effects) due to Yukawa interaction for up-type quark masses generate significant flavor mixing in the LL sector when one considers the high scale SUSY breaking scenario where the mediation of the SUSY breaking takes place at a high energy scale. Given the non-negligible mixing in the LL sector at the electroweak scale, the bound from the hadronic EDMs thus practically constrains the flavor mixing in the RR sector. It has been shown that with the parameters satisfying the constraint, the contribution to the mixing-induced CP asymmetry of the $B_d \rightarrow \phi K^0$ from the RR mixing should be negligibly small. Thus we focus on the LL squark mixing.

In this talk, which is based on the works with Mitsuru Kakizaki and Masahiro Yamaguchi in Ref. [5,6], we show that the hadronic EDMs provide a new constraint on the LL squark mixings between 2 – 3 generations, through the chargino mediated diagrams. We also revisit the SUSY contributions to the mixing-induced CP asymmetry of $B_d \rightarrow \phi K^0$, considering the experimental bound from the hadronic EDMs as well as that from $\text{Br}(b \rightarrow s\gamma)$.

2. LL Squark Mixing

Here we point out that the LL mixing is constrained by the hadronic EDMs. We first

emphasize that chargino-mediated processes can also provide large contributions to the CEDM of the strange quark d_s^C because there are diagrams which are enhanced by the top Yukawa coupling constant. In the presence of $2 - 3$ mixing in the LL sector, d_s^C is induced by the double mass insertion diagram and is evaluated as

$$d_s^C \simeq \frac{1}{8\pi^2} \frac{G_F}{\sqrt{2}} m_t^2 m_s V_{ts} \frac{|A_t \mu| \tan \beta}{m_{\tilde{q}}^4} M_a(x) |(\delta_{LL}^u)_{32}| \sin \theta_a, \quad (4)$$

$$\begin{aligned} &\simeq 2.8 \times 10^{-24} e \text{ cm} \times |(\delta_{LL}^u)_{32} \sin \theta_a| \\ &\quad \times \left(\frac{\tan \beta}{20} \right) \left(\frac{|\mu|}{250 \text{ GeV}} \right) \left(\frac{|A_t|}{500 \text{ GeV}} \right) \left(\frac{m_{\tilde{q}}}{500 \text{ GeV}} \right)^{-4} \left(\frac{M_a(x)}{-0.31} \right). \end{aligned} \quad (5)$$

where the loop function $M_a(x)$ is defined in Ref. [5] and $x \equiv |\mu|^2/m_{\tilde{q}}^2$. Here θ_a parameterizes the CP violating phase as $\theta_a = \arg[A_t \mu (\delta_{LL}^u)_{32}]$. Note that one of the flavor mixings is now given by the CKM matrix. Thus compared with the experimental upper limit from the neutron EDM, we obtain

$$|(\delta_{LL}^u)_{32} \sin \theta_a| \lesssim 0.07(0.09), \quad (6)$$

from the neutron EDM. Here the number in the parentheses represents the assumption of the Pecci-Quinn (PQ) symmetry. The relevant parameters are taken to be $\tan \beta = 20$, $|\mu| = 250 \text{ GeV}$ and $|A_t| = m_{\tilde{q}} = 500 \text{ GeV}$. Therefore we conclude that the $\tilde{t}_L - \tilde{c}_L$ mixing angle or the CP violating phase must be suppressed at the level of $O(0.1)$ when $\tan \beta$ is large, in the light of the result of the neutron EDM experiment. We stress that this constraint is severer than that obtained from the branching ratio of the process $b \rightarrow s\gamma$, by about one or two orders of magnitude depending on mass spectra of superparticles.

3. B Physics

Finally we investigate the implication on $b \rightarrow s$ transition processes of B mesons from the constraints by the hadronic EDMs as well as $\text{Br}(b \rightarrow s\gamma)$. Since the RR squark mixing is suppressed sufficiently, we consider the contributions from the LL mixing. The SUSY contributions to the processes are dominated by gluino mediated diagrams and thus we need the experimental constraint on the down-type squark mixing. Indeed the bound from the hadronic EDMs obtained above is on the up-type one, but notice that $(\delta_{LL}^u)_{ij}$ and $(\delta_{LL}^d)_{ij}$ are related to each other because of the $SU(2)_L$ symmetry. In fact, in the superCKM basis, one finds that

$$(\delta_{LL}^d)_{32} \sim (\delta_{LL}^u)_{32} + \lambda (\delta_{LL}^u)_{31} + O(\lambda^2) \quad (7)$$

in terms of the Wolfenstein parameter $\lambda \sim 0.2$. Hence in the absence of accidental cancellation or hierarchy among the parameters the bound on $(\delta_{LL}^u)_{32}$ is translated into that on $(\delta_{LL}^d)_{32}$.

Let us now discuss the mixing-induced CP asymmetry of $B_d^0 \rightarrow \phi K^0$, which is known to be one of the most interesting modes. In Fig. 1, we show the numerical result, where the constant contours of $S_{\phi K^0}$ are shown. The constraints from the $b \rightarrow s\gamma$ branching ratio,

for which we take a rather conservative bound, $2.0 \times 10^{-4} < \text{Br}(b \rightarrow s\gamma) < 4.5 \times 10^{-4}$, and from the hadronic EDMs, that is, the neutron EDM with/without the assumption of the PQ symmetry, are also displayed on the graph. Here we show the result of $|(\delta_{LL}^d)_{23}| = 0.1$ with maximal complex phase. As a reference, we also fix the soft parameters as $m_{\tilde{g}}^2 = m_{\tilde{q}}^2 = (500 \text{ GeV})^2$ and $A_t = 500 \text{ GeV}$. And we take the other model parameters: the Win mass $M_2 = 250 \text{ GeV}$ and the Higgs mass parameters $m_{H_d}^2 = -m_{H_u}^2 = (250 \text{ GeV})^2$. We find that the CP asymmetry becomes large as μ_H or $\tan \beta$ increases. Consequently, from Fig. 1, we perceive that the contribution from the LL squark mixing to $B_d \rightarrow \phi K^0$ can become as large as $S_{\phi K} \lesssim 0$.

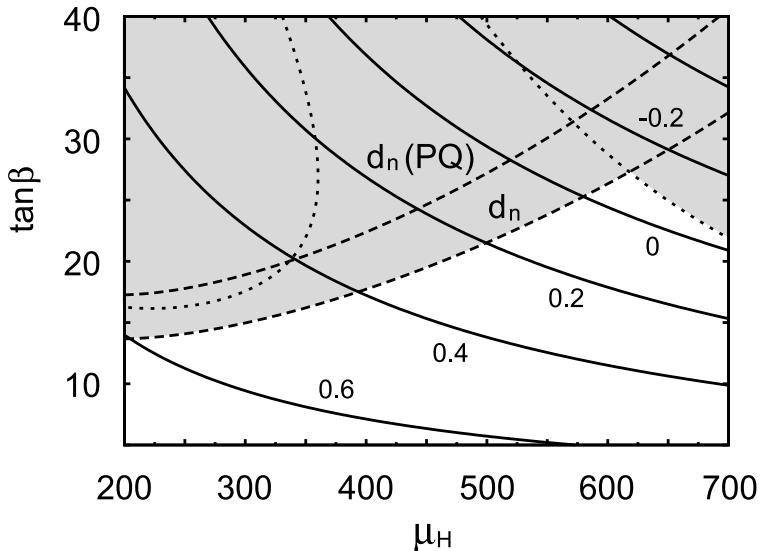


Figure 1: Constant contours of the CP asymmetry $S_{\phi K^0}$ (solid) when the LL down-type squark mixing is $|(\delta_{LL}^d)_{23}| = 0.1$ with maximal phase. The contours of the $b \rightarrow s\gamma$ branching ratio (dotted, in units of 10^{-4}) and the CEDM of the strange quark which is constrained from the neutron EDM (dashed) are also shown. The soft parameters are $m_{\tilde{g}}^2 = m_{\tilde{q}}^2 = (500 \text{ GeV})^2$ and $A_t = 500 \text{ GeV}$.

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